WATERTOWN ARSENAL

LABORATORY

REPORT

NO. WAL 112/75
O.O. PROJECT NO. TB4-1A

THE EFFECT OF DIMENSIONAL CHANGES ON

SQUARE V-NOTCHED CHARPY BARS
(Sixth Partial Report on Temper Brittleness)

BY

D. C. BUFFUM
Physicist

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DATE 13 January 1949

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WATERTOWN, MASS.

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TITLE

The Effect of Dimensional Changes
on Square V-Notched Charpy Bars

OBJECT

To determine the effect of reducing the cross-sectional area upon the transition temperature of square V-notched Charpy impact specimens.

SUMMARY

Impact data over a range of temperatures are presented for the standard and for several sub-sized, square, V-notched Charpy specimens. These data are for one steel which has been given a single heat treatment.

The effects of a reduction in cross-sectional area and of small changes in the notch upon the temperature of transition from ductile to brittle fracture are shown.

The transition temperatures are taken from graphs in which the impact energy and the percent fibrous fracture are plotted as functions of the testing temperatures. Four of the many definitions for transition temperature are used to compare the data.

The impact energy values obtained from breaking sub-sized specimens on the small machine have been in good agreement with those values obtained from breaking similar specimens on the standard machine.

CONCLUSIONS

1. Regardless of size of specimen, the most uniform transition temperature, considering several criteria, is obtained using the definition: "The transition temperature is the lowest temperature at which the specimen breaks with a one hundred percent fibrous fracture, as taken from the percent fibrous fracture vs. testing temperature curve."

2. The transition temperature is decreased by reducing the cross-sectional area of the specimen.

3. The effect of small changes in the notch radius is negligible. Therefore, since it would facilitate machining, it is suggested that the standard notch radius be used in all bars.

4. The shallow notch increases the impact energy by increasing the area under the notch; however, the transition temperature is lowered.

5. When it is necessary to reduce the size of the Charpy specimen it appears advantageous to use as large a sub-size specimen as possible with the standard V-notch (group II).

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APPROVED:

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Director of Laboratory

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INTRODUCTION

With the necessity of using smaller sized test specimens increasing, it is desirable to know how the data obtained from sub-sized specimens compare with those from the so-called standard specimens. It is the purpose of this report to correlate the data from sub-sized V-notched Charpy impact bars with data from standard V-notched Charpy specimens.

Of the literature reviewed, only one paper revealed previous work on the effect of the size of V-notched Charpy specimens on the transition temperature. This was a report[1] from this Arsenal which indicated that the apparent transition temperature is decreased with reduction of the cross-sectional area. However, it should be noted that the specimens in this previous investigation did not have their dimensions reduced proportionately.

MATERIAL AND TEST PROCEDURE

In the present report three groups of sub-sized specimens were used.

Group I - all dimensions except length decreased proportionately.

Group II - same as Group I except that the radius at the base of the notch was that of the standard sized specimens.

Group III - same as Group I except that the notch was shallower and had a smaller radius at the base.

If standard machines are to be used for testing Charpy bars, it is impossible to reduce the length of the bar proportionately with the other dimensions, therefore most tests were made with bars of standard length.

The specimens used in this investigation were machined from hot rolled SAE 3140 bar stock of 5/8" diameter. The chemical analysis showed the material to be of the following composition (in percent):

C	Mn	Si	S	P	Ni	Cr	Mo	V
.385	.79	.30	.028	.015	1.26	.77	.02	$<$.01

Blanks from which the specimens were machined were heat treated in .420" squares 2.16" long. They were austenitized at 925°C (1700°F), held 1 hour at temperature and air cooled. After this they were tempered at 650°C (1200°F) for 1 hour and water quenched. This treatment produced a structure of tempered bainite with about 5 percent tempered martensite.

1. D. E. McCarthy & J. H. Hollomon, "Investigation of Sub-Sized Charpy Specimens" WAL 112/48.

The austenitic grain size was ASTM 8 and the Rockwell "C" hardness of the tempered specimens was 18-22. After heat treating, the specimens were machined to the dimensions indicated in Table I. Ten specimens of each size were used to obtain the transition curves.

With the exception of the short length specimens, all bars were tested on a standard 217 foot-pound Charpy machine whose striking velocity is 16.8 feet per second. The standard gage length of 1.57 inches was used. The striking head was designed according to the specifications of the American Society for Testing Materials.[2]

The short length bars were tested on a small impact machine with a capacity of 16 foot-pounds. The striking velocity was 11.5 feet per second. The striking edge had a radius of .109" and the distance between supporting edges of the specimen anvils was 1.0 inches.

RESULTS AND DISCUSSION

The data (Table II) collected in this investigation are plotted in Figures 1 and 2. Figure 1 presents the percent fibrous (ductile) fracture of the specimens as a function of the testing temperature. Figure 2 presents the impact energy of the specimens as a function of the testing temperature.

In analyzing impact data, there are many criteria by which the investigator may compare the data. In recent years many of the investigators have used either the transition temperature or the transition range. The definitions for transition temperature or range, however, are very numerous. In this paper the data will be analyzed using four of the many possible definitions. The first of the following definitions is the one being used at this Arsenal for transition temperature.

1. The transition temperature is the lowest temperature at which a one hundred percent fibrous fracture is obtained, as taken from the percent fibrous vs. testing temperature curve.

2. The transition temperature is that temperature at which the fracture is fifty percent fibrous, as read from the percent fibrous vs. testing temperature curve.

3. The transition temperature is that temperature at which the energy is one-half the value obtained at the lowest temperature at which the fracture is one hundred percent fibrous.

2. ASTM Standards, 1947 Supplement, Part 1A, pp. 381-393.

4. The transition temperature is that temperature at which the energy absorbed is one-half the sum of the values obtained at the lowest temperature at which the fracture is one hundred percent fibrous and the highest temperature at which the fracture is zero percent fibrous.

Table III presents the transition temperatures for various groups of bars as obtained using the above definitions.

On studying Table III it will be noted that the most uniform transition temperature, regardless of specimen size, is obtained by using definition 1. Also note that in any group of specimens the reduction in cross-sectional area decreases the transition temperature. This verifies the earlier information.[1]

As shown by studying the groups, the effect of changing the radius of the notch on any given sized bar is small. Therefore, since it would facilitate the machining of specimens to use the radius of the standard bar in all specimens (Group II), it is recommended that this be done.

The use of the shallow notch (Group III) increases the impact value obtained from fracturing the specimens; however, the transition temperature decreases. The increase in impact value is believed to be caused by the increase in the cross-sectional area under the notch of the specimen.

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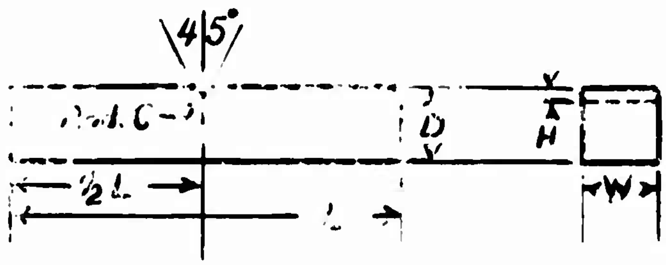
1. See page 3.

TABLE I

Dimensional Characteristics of Specimens



All dimensions to be ± .002" except radius at bottom of notch which shall be within .001" and the angle of the notch which shall be ± 1 degree.

Dimensions (Inches) of Specimens

Specimen Type	L	D and W	H	C
		Group I		
1/2	2.16	.197	.039	.005
1/2S*	1.40	.197	.039	.005
3/4	2.16	.296	.059	.0075
		Group II		
1/2R**	2.16	.197	.039	.010
1/2S*R**	1.40	.197	.039	.010
3/4R**	2.16	.296	.059	.010
		Group III		
1/2N***	2.16	.197	.0195	.0025
3/4N***	2.16	.296	.039	.005
		Standard		
Std****	2.16	.394	.079	.010

* S short length
** R standard notch radius
*** N shallow notch
**** Std standard V-notched Charpy bar

TABLE II

IMPACT TEST DATA

Specimen No.	Rockwell "C" Hardness	Testing Temperature °C	Impact Energy Ft-Lbs	Percent Fibrous Fracture
		Group I Type 1/2		
S11	20.0	+26	11.4	100
S20*	21.5	+26	11.2	100
S14	20.0	0	10.9	100
S15	20.0	-20	10.6	100
S17	18.5	-30	10.3	100
S12	20.0	-40	9.4	80
S18	18.0	-60	8.6	40
S19*	19.5	-60	8.2	40
S13	22.0	-78	4.1	20
S16	20.0	-120	2.8	0

* Small testing machine used to break these specimens.

Specimen No.	Rockwell "C" Hardness	Testing Temperature °C	Impact Energy Ft-Lbs	Percent Fibrous Fracture
		Group I Type 1/2 S		
S54	20.5	-40	8.9	80
S55	19.5	-60	8.8	60
S56	19.0	-78	7.0	40
S57	19.0	-100	4.0	20
S52	19.0	-120	3.8	< 10
		Group I Type 3/4		
S31	20.5	+26	35.8	100
S34	21.0	0	34.2	100
S37	20.5	-10	35.0	100
S35	19.5	-20	27.6	80
S32	19.5	-40	26.9	50
S38	20.0	-40	24.3	40
S39	20.0	-60	13.6	25
S33	19.5	-78	10.6	5
S36	20.0	-100	6.6	0

TABLE II (Cont.)

Specimen No.	Rockwell "C" Hardness	Testing Temperature °C	Impact Energy Ft-Lbs	Percent Fibrous Fracture
		Group II Type 1/2 R		
S65	19.0	+22	12.6	100
S80	18.5	0	13.3	100
S103	18.0	-20	12.6	100
S104	19.0	-30	10.6	80
S66	19.5	-40	10.3	80
S118	18.0	-55	9.2	60
S79	18.0	-70	7.2	30
S112	18.5	-90	6.4	10
S113	18.0	-120	3.3	5
		Group II Type 1/2 SR		
S64	18.0	+22	13.5	100
S75	18.5	0	13.4	100
S89	18.5	-20	14.2	100
S90	18.5	-30	14.2	100
S68	18.0	-40	13.8	80
S116	18.5	-55	13.2	75
S74	18.0	-70	10.0	50
S109	18.5	-90	9.3	40
S110	18.0	-120	5.8	10
		Group II Type 3/4 R		
S62	19.0	+22	40.3	100
S87	18.5	0	39.1	100
S101	20.0	-10	33.8	90
S100	19.5	-20	33.8	90
S77	19.0	-40	22.9	50
S115	19.5	-55	18.7	40
S86	19.5	-70	12.6	20
S105	19.5	-90	11.8	5
S114	19.5	-120	3.8	0

TABLE II (Cont.)

Specimen No.	Rockwell "C" Hardness	Testing Temperature °C	Impact Energy Ft-Lbs	Percent Fibrous Fracture
		Group III **Type 1/2 N**		
S1	20.5	+26	17.7	100
S9	20.5	-10	16.8	100
S2	21.0	-40	16.4	100
S5	19.5	-50	11.8	60
S8	18.5	-50	14.4	50
S4	20.5	-60	12.4	50
S3	20.0	-78	10.0	25
S10	20.0	-100	4.3	0
S6	20.5	-120	2.3	0
		Group III **Type 3/4 N**		
S21	19.5	+26	50.1	100
S24	20.0	0	46.6	100
S27	20.5	-10	46.2	100
S25	20.0	-20	37.4	80
S30	19.5	-20	37.8	80
S22	19.0	-40	35.4	60
S29	19.5	-40	36.2	75
S28	19.5	-60	19.1	25
S23	19.5	-78	18.1	15
S26	19.5	-120	8.3	0
		Standard **Std Heat Treatment 1**		
S41	20.0	+26	90.8	100
S45	19.0	+10	87.2	100
S44	19.0	0	63.2	80
S47	19.0	0	78.1	100
S49	19.0	-20	79.6	100
S50	19.5	-30	51.0	60
S42	19.0	-40	41.5	40
S48	19.5	-40	39.1	30
S43	19.0	-78	19.1	5
S46	20.0	-100	13.3	0

TABLE II (Cont.)

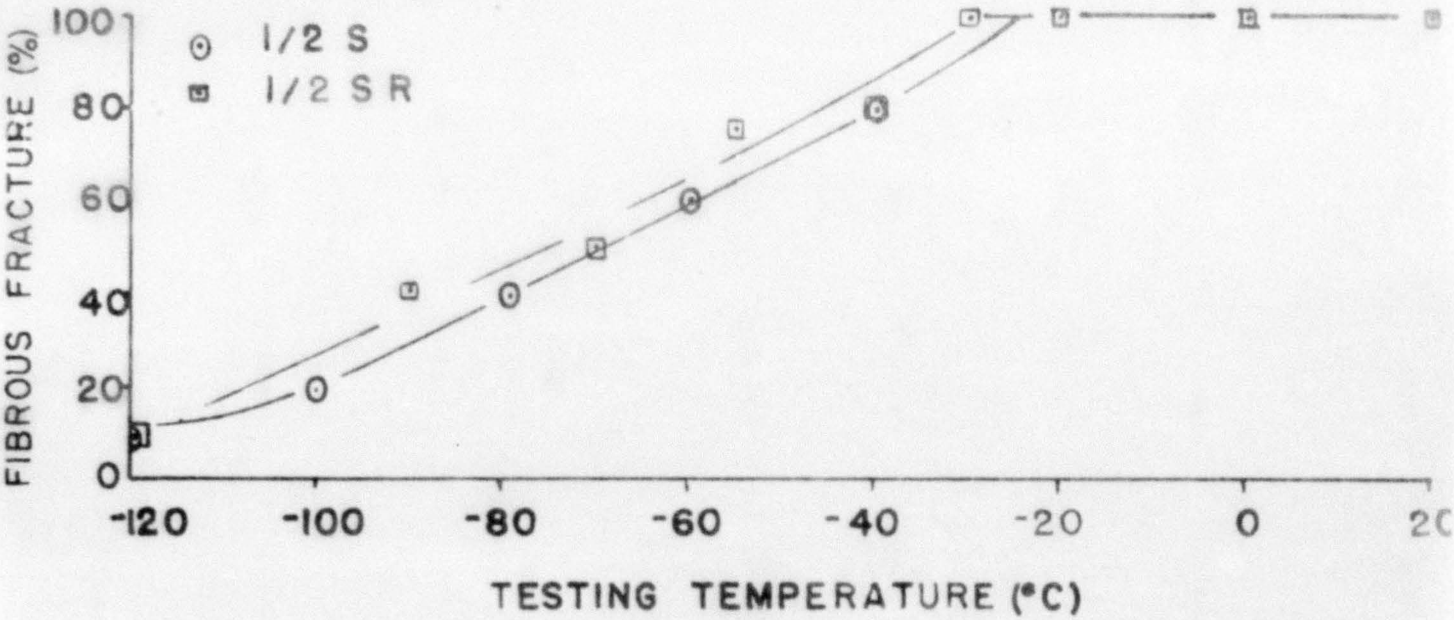
Specimen No.	Rockwell "C" Hardness	Testing Temperature °C	Impact Energy Ft-Lbs	Percent Fibrous Fracture
		Standard	Std Heat Treatment	
871	18.5	+22	94.9	100
883	19.5	0	98.5	100
892	18.5	-10	99.5	100
893	19.5	-15	89.3	100
884	19.0	-20	68.4	80
897	18.5	-30	52.8	40
872	19.5	-40	34.2	30
878	19.5	-70	26.5	10
898	19.5	-90	18.7	0

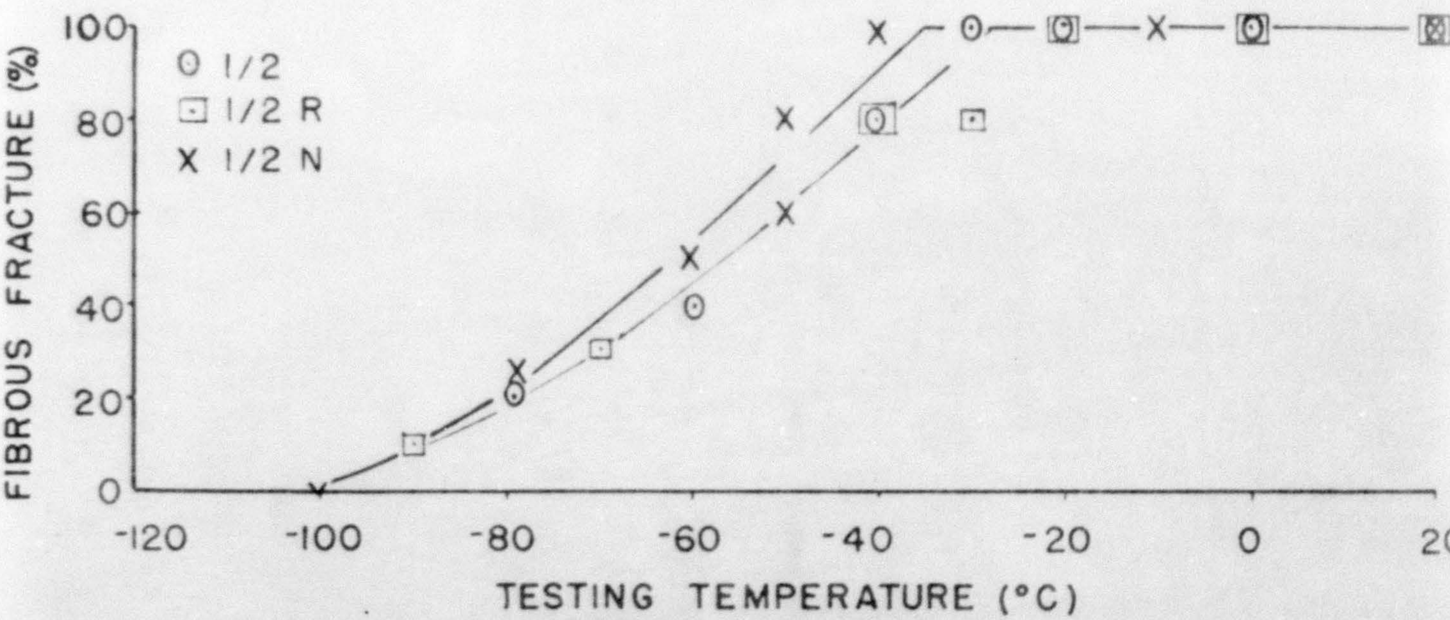
TABLE III

Transition Temperatures (in °C)

	Specimen Groups									
	I			II			III		Standard*	
Definition	1/2	1/2S	3/4	1/2R	1/2SR	3/4R	1/2N	3/4N	H.T. 1	H.T. 2
1	-28	-25	-10	-28	-30	-13	-30	-13	-19	-16
2	-55	-70	-37	-55	-75	-75	-63	-45	-33	-26
3	-73	-95	-53	<-90	-108	-108	-82	-55	-38	-33
4	-69	-83	-43	-53	-70	-70	-70	-48	-32	-27

* Standard Heat Treatment 1 and Heat Treatment 2 values are taken from curves made from two separate groups of standard size bars heat treated at different times.


FIBROUS FRACTURE (%)
100
80
60
40
20
0
-120
-100
-80
-60
-40
-20
0
20
TESTING TEMPERATURE (°C)
1/2 S
1/2 SR


FIBROUS FRACTURE (%)
100
80
60
40
20
0
-120
-100
-80
-60
-40
-20
0
20
TESTING TEMPERATURE (°C)
1/2
1/2 R
1/2 N

1

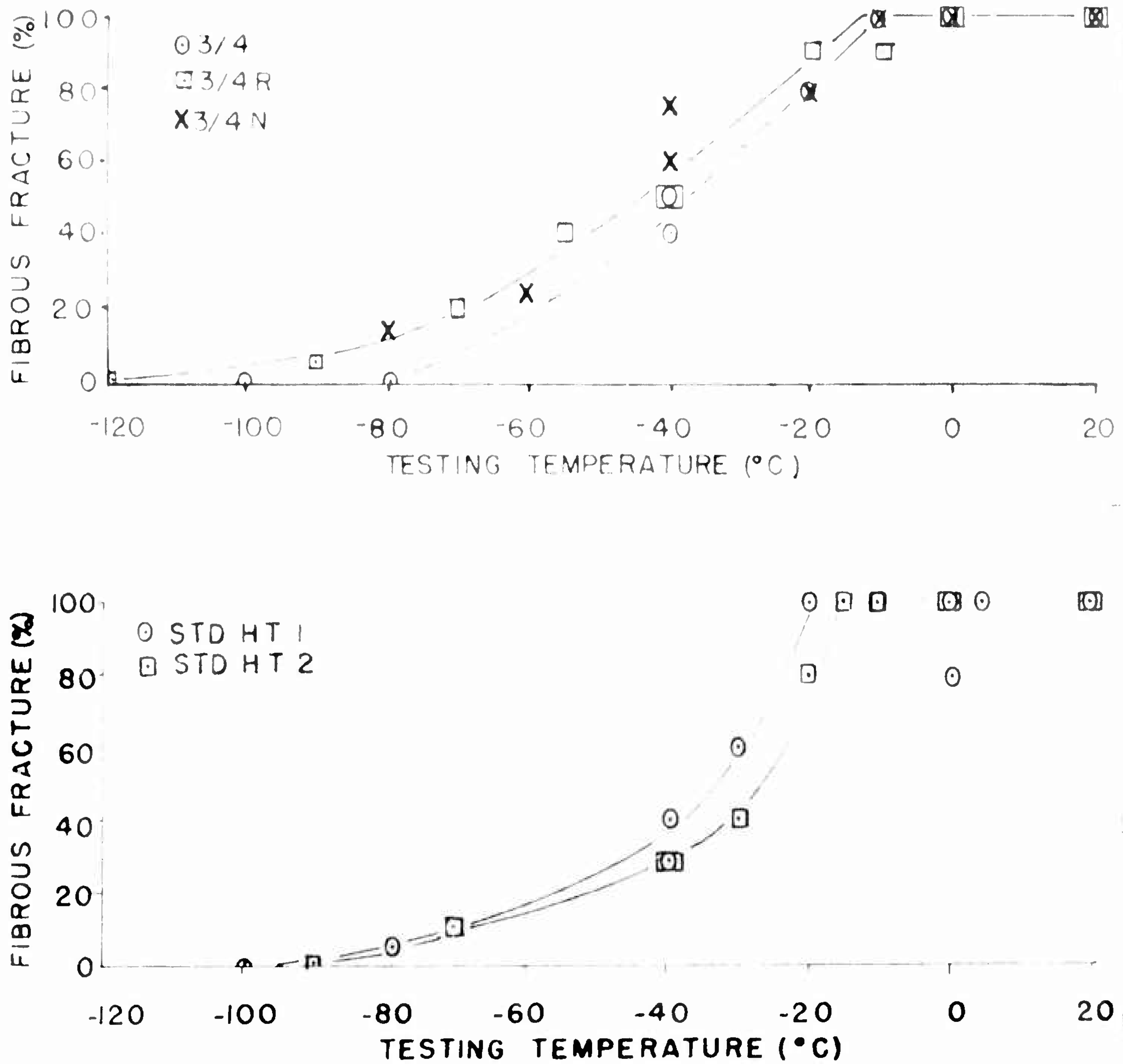
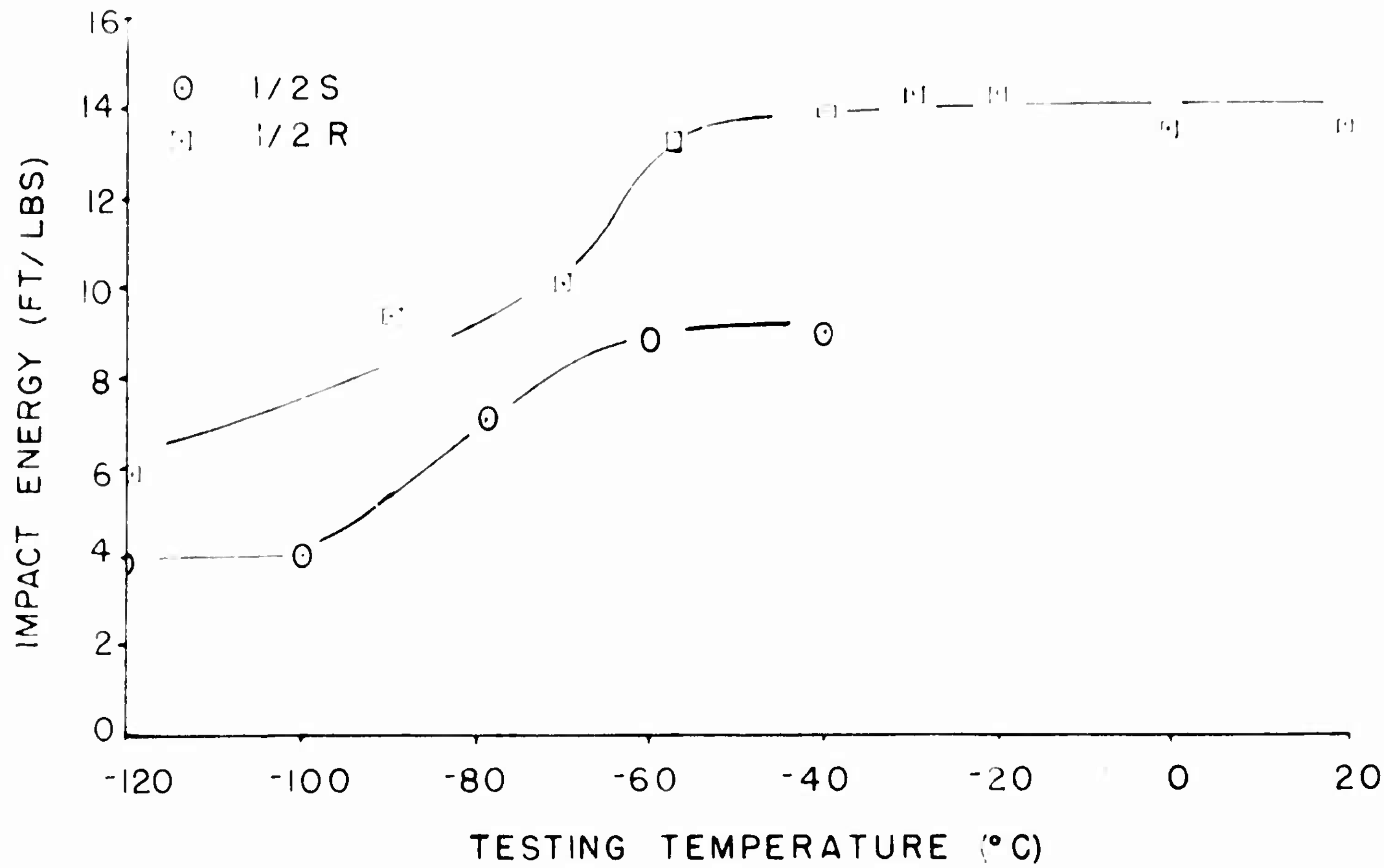
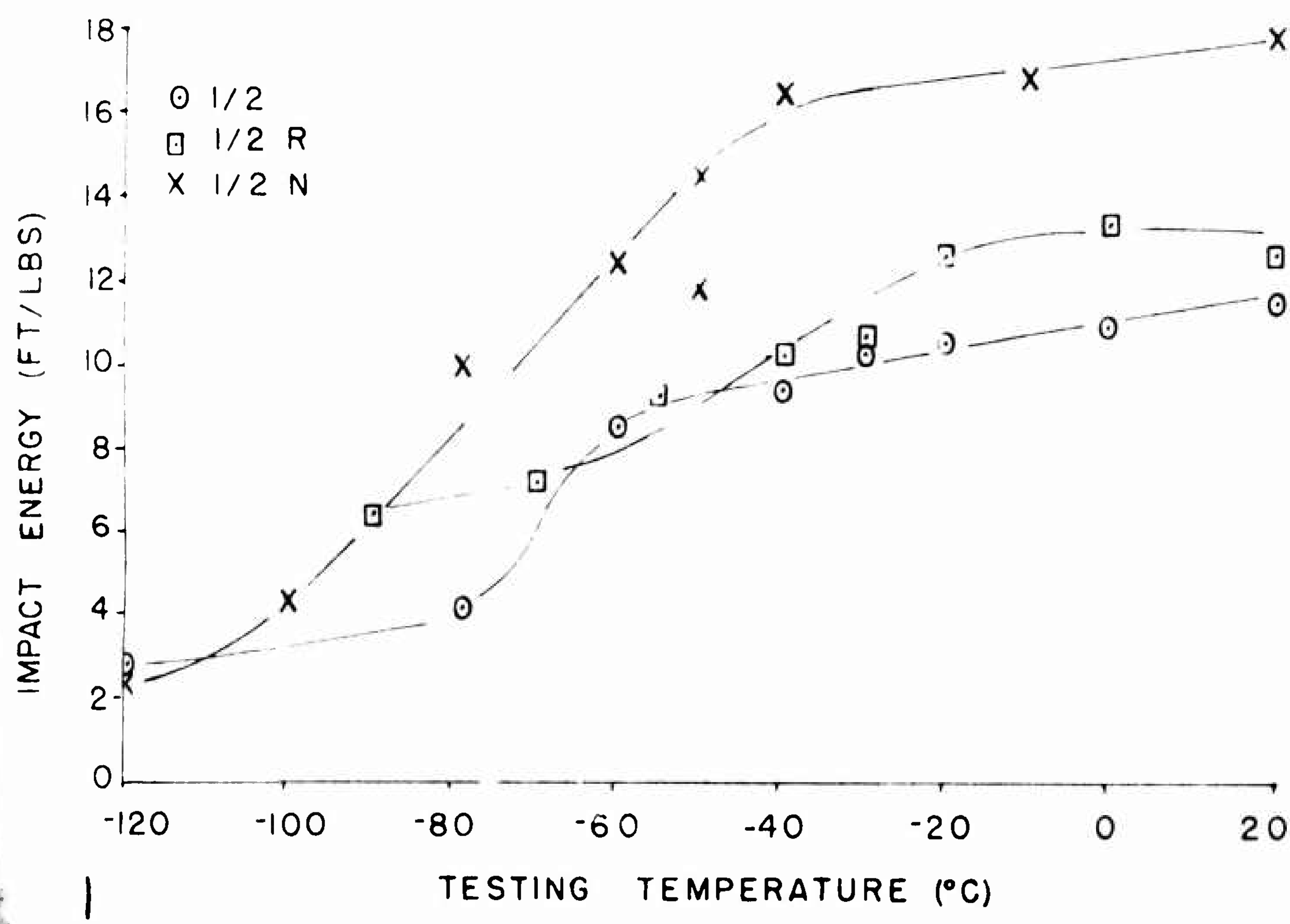


FIGURE 1 PERCENT FIBROUS FRACTURE AS A FUNCTION OF TESTING TEMPERATURE

LEGEND S-SHORT LENGTH R-STANDARD NOTCH RADIUS N-SHALLOW NOTCH RADIUS



16
14
12
10
8
6
4
2
0
IMPACT ENERGY (FT/LBS)
⊙ 1/2 S
⊡ 1/2 R
-120
-100
-80
-60
-40
-20
0
20
TESTING TEMPERATURE (°C)



18
16
14
12
10
8
6
4
2
0
IMPACT ENERGY (FT/LBS)
⊙ 1/2
⊡ 1/2 R
X 1/2 N
-120
-100
-80
-60
-40
-20
0
20
TESTING TEMPERATURE (°C)

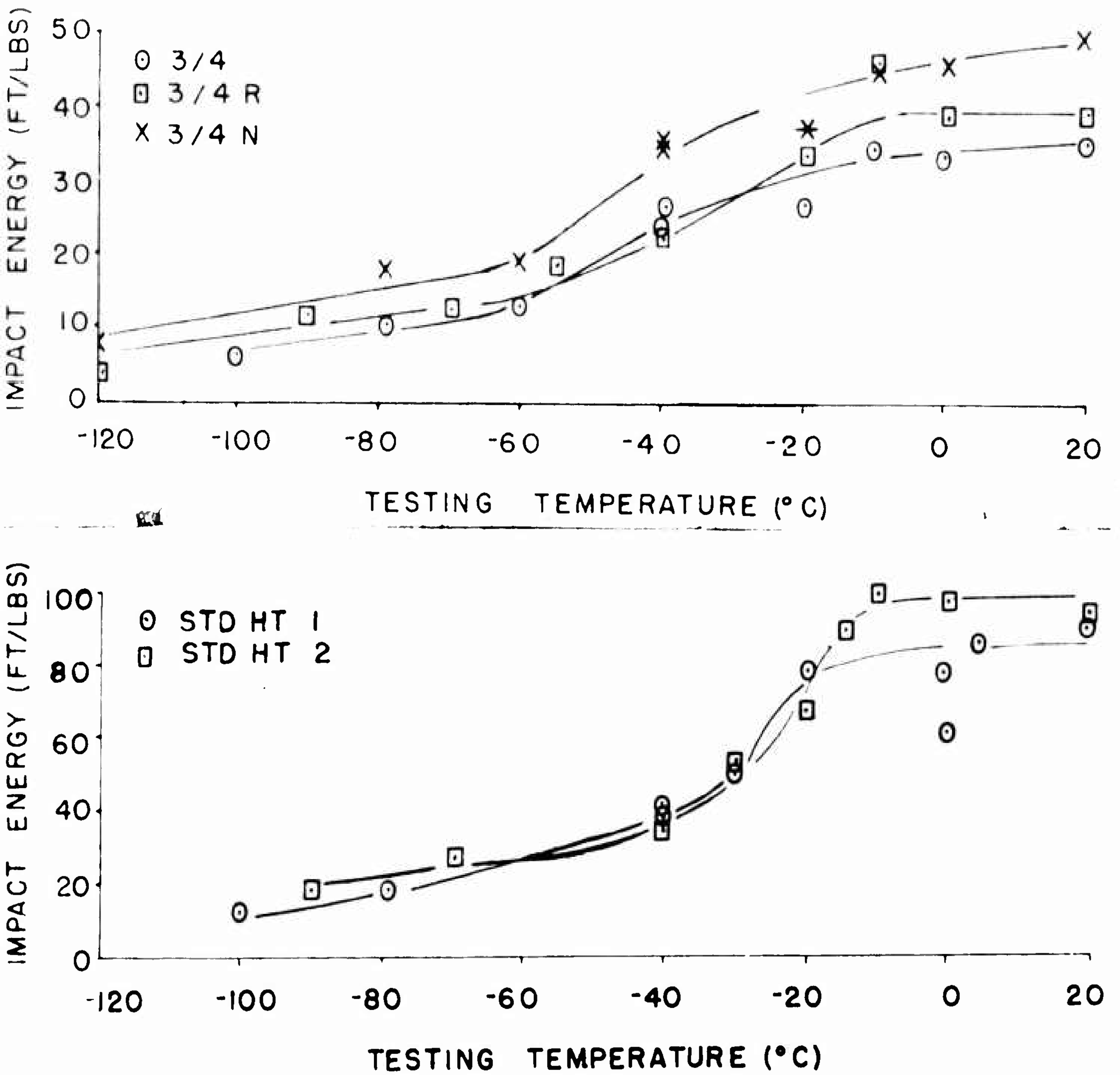


FIGURE 2 IMPACT ENERGY AS A FUNCTION OF TESTING TEMPERATURE

LEGEND S- SHORT LENGTH R- STANDARD NOTCH RADIUS N- SHALLOW NOTCH RADIUS